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# The Influence of a growing urban tree canopy on municipalities and urban stormwater: a cost analysis

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# The Influence of a growing urban tree canopy on municipalities and urban stormwater: a cost analysis

by

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**Abstract**

As many cities and local municipalities face the increasing problems associated with climate change, many are turning to trees to rebuild the natural environment and ecosystems within their urban cores. Many are choosing to increase their tree canopies in order to conserve energy, remove carbon dioxide and other pollutants from the air, provide habitat for animals, and much more. While urban tree canopies have countless benefits, and should be protected and expanded, they also have costs. These costs are often direct dollar values that fall onto the responsibility of the local municipalities. Costs include maintenance, debris cleanup, irrigation, infrastructure repair, and much more. One specific cost that has little research to report on is the cost associated with stormwater management and water quality control in local waterways. Tree debris, mostly leaves, can cause a threat to local waterbodies by depositing excess amounts of nitrogen and phosphorus to the waterway. This can lead to eutrophication of waterways, algae blooms, and decreased dissolved oxygen levels in the water. As tree canopies increase, the need to collect this debris increases. This is done mainly through increasing street sweeping efforts. This thesis has analyzed the costs associated with street sweeping in the City of Orlando. Not all leaves are collected through street sweeping, and many will still end up in waterways, impacting water quality. This thesis also has analyzed the cost associated with leaves entering waterways in City of Orlando lakes by quantifying the cost of nitrogen and phosphorus loading to waterways. These are the two main areas where future costs will increase as tree canopies increase. Therefore, it is important for all cities and municipalities to prepare for these costs as they choose to expand their tree canopies. While it is incredibly important for cities and municipalities to expand urban tree canopies, it must be done in a strategic way that uses "right tree, right place" habits as well as budgets for the immediate costs as well as long term costs.

**The Influence of a growing urban tree canopy on municipalities and urban stormwater: a cost analysis**

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## 1. Introduction:

Many governments around the world are beginning to adopt policies that address climate change. More and more, people are seeing the impact climate change has had on the environment, and are changing behavior to decrease any further impact it may have on our future environment.

While larger governments have the power to make change, the real change is going to come from small, local governments such as cities. Cities hold a special power in their ability to see direct impacts from their policy decisions. According to the United Nations Department of Economic and Social Affairs, 55% of the world's population lives in an urban area or city, and that number is expected to rise to 68% by 2050. This means that changes in these urban areas have the ability to impact many people. Cities and local governments become the catalyst for change on a national and even international level.

> *Cities are leading the charge against climate change, and one of the reasons is that they share so much in common – what works for one city usually holds valuable lessons for many others. The more we help city leaders collaborate and share their wisdom, the faster they can make progress." - U.N. Secretary-General's Special Envoy for Cities and Climate Change and former New York City Mayor Michael R. Bloomberg*

Many cities across the world and across the United States are recognizing their unique role in addressing climate change, and are making policy changes and creating programs that address climate change. Cities are adopting energy policies to urge businesses to become more sustainable. They are making proclamations to conserve water and reduce waste. They are incentivizing businesses and residents to make sustainable choices. They are making structural changes as well as policy changes. Many local governments are also turning to the power of nature to offset the impacts humans have had on the environment.

Combating climate change will require many new policies, changes in infrastructure, and far more complicated and time consuming actions. However, many local governments are seeing that change can also come from simple actions intended to return their concrete jungles, paved paradises, and urban atmospheres back to a more natural environment, as it once was. Increased green spaces in cities have many positive effects, both in a practical sense and in a social and aesthetic sense.

It is no surprise that green spaces are good for the environment. After all, that's how nature intended it to be before humans wiped out all of the green in favor of asphalt, buildings, and concrete, which has led to increased flooding and erosion, and decreased natural habitats. Green spaces also add social and aesthetic value that is very important to urban areas. This has created an opportunity for cities across the United States to strategically increase green space in a way that compliments their policies to combat climate change, reduce carbon dioxide emissions, improve water quality and general hydrology, increase natural habitats, improve air quality, and improve quality of life altogether. Cities are beginning to use techniques such as green infrastructure and low impact development to assist with stormwater management and energy reductions. Many cities are also choosing to take a much simpler route: increasing their urban canopy of trees.

With all of the sophisticated techniques out there, it is surprising to remember that something so basic as a tree can still have a major impact on our environment.

Many cities are recognizing this and choosing to put programs into place intended to increase their urban tree canopy.  Programs may include planting trees in public rights of way, giving away trees to the public, urging residents to plant trees in their own private property, and increasing trees in other public and private spaces.

There is no doubt that trees are beneficial to the environment.  They sequester carbon dioxide from the atmosphere, their shade can lower the temperature in hot summer months and offset the urban heat island effect, they provide a habitat for animals, and much more which is fully fleshed out in the Literature Review of this paper.  However, trees, like any public improvement, have costs that often go unseen and unaddressed when programs are put in place with the intent to increase the urban canopy.

There are many obvious costs that are associated with trees, such as maintenance and irrigation; there are also many costs that are not obvious.  All of these costs often fall on the local government and tax dollars.  This includes infrastructure repair from tree root destruction, removal of leaves from streets via street sweeping, liability issues, water quality concerns due to tree leaf litter, etc.

The purpose of this thesis is to uncover the costs that are associated with trees and how to plan for these.  A traditional approach would be to perform a cost-benefit analysis of trees in an urban environment.  However, many studies have already been done this way.  More importantly, the entities who experience the benefits are not those who experience the costs.  Therefore, this thesis will do a cost analysis on trees, focused on the costs incurred by local governments.  Many costs associated with trees are not planned for and become long-term burdens to the local government and utility providers. This thesis will attempt to put a cost to leaf fall associated with trees. Large amounts of leaves entering stormwater systems and local water bodies have a negative impact on water quality in open bodies of water. To date, no research has fully uncovered the cost of trees in this sense.

This thesis will provide an important and useful framework for local governments to use while planning for increased numbers of trees. The goal of this thesis is to uncover a missing piece of existing cost benefit analyses of urban trees: the costs associated with urban stormwater management.

## 2. Literature Review

In order to create a comprehensive cost analysis of urban trees, it is important to first understand urban trees and motivations to increase an urban canopy. It is also important to understand the costs and benefits that are currently known and have been studied regarding urban trees. A great deal of research has been done to uncover the benefits of trees, specific and nonspecific to urban trees. A large amount of research has also been done to address the costs of trees, though not nearly to the same degree as what has been done to study the benefits.

### 2.1 Overview of Urban Trees/Expanding an Urban Canopy

The greater the tree cover, the greater the influence of the trees on the environment, whether good or bad. While this literature review will show that many studies agree that benefits outweigh the costs of trees, there is a disparity in who bares the costs versus the benefits. The benefits are largely intangible, widespread and shared amongst the community while the costs are direct dollar values that fall mostly on local government. Furthermore, while many local governments are choosing to adopt programs to expand their urban canopies, they are not budgeting properly for the long-term costs of having a denser canopy cover. This thesis will aim to analyze the costs that are directly taken on by the local municipalities, so these entities can prepare and budget for growing urban forests.

**2.2 History of trees in urban environments**

Trees have long been a part of human culture. People have tended to connect themselves to trees in various ways. They become destinations, a piece of history, points of pride in communities, we name our streets after them, we awe at their majesty, join volunteer projects to plant them, and take ownership of those that we plant. Trees connect urban dwellers with a piece of nature in an otherwise concrete world. They were planted in cities long before we began quantifying their numerous benefits.

Looking at American history, tree planting in urban environments began to become prevalent during the industrial revolution, when cities became more dense, air quality declined, and access to nature was more challenging (Pincetl et al, 2013). During that time, many looked to mimic European cities that went through similar industrial growth and declining public health, air quality, and quality of life. In the mid 1850's, Britain passed a reform that aimed to enhance public health by increasing access to public space and recreation. Included in this was an initiative to plant trees in public rights of way. This quickly spread to other European countries, and eventually the United States (Pincetl et al, 2013). In fact, Fredrick Law Olmstead was strongly influenced by his experience in parks in England during this period, and incorporated many of these concepts in his most famous urban parks, including Central Park in New York City and Highland Park in Rochester, New York (Lawrence, 2006).

It would appear that from that moment on, the desire to green the urban environment grew. In 1872, a former governor of Nebraska, J. Sterling Morton, founded Arbor Day as a national day of planting, a day that is still celebrated today (Pincetl et al, 2013). Tree planting has since become an obsession, with non-profits, citizen groups, and other organizations coming together to partake and plant trees in the public right-of-way and private land.

While trees have had a large influence on early American history and the design of cities, they continue to influence cities today. More recent policies like the 1978 Cooperative Forestry Assistance Act of Congress first quantified benefits of trees and encouraged more trees to be planted in urban environments. Other programs like Tree City USA, which began in 1976, still runs strong today. Trees are deeply seeded in our history and remain an important part of our present and future (Pincetl, 2013). This history of tree plantings in urban environments shows a longstanding support from nonprofits, federal government, local governments, and citizens alike. As concerns about climate change grown, “it is scarcely surprising that mayors of many cities have embraced urban forestry as a means of mitigating environmental impacts,” (Pincetl, 2013).

As one author writes:

> *"Trees have a particular and powerful hold on the American conceptions of what is good in nature and the environment. As we attempt to cope with environmental crises, we increasingly enlist trees as agents of our stewardship over nature." (Cohen, 2004).*

However, as we move into the future with tree planting programs, it is imperative to understand what impact these programs will have and what costs may be associated, so local municipalities can begin to budget accordingly.

Sometimes, the value of trees and costs associated don't make total budgetary sense, and the price tag of a tree is extreme. During a recent construction project at a former Fannie Mae headquarters in New York City, a 600,000 pound oak tree uprooted and moved in order to be saved (Hagarty, 2019) Deemed a "heritage tree," this tree had value far greater than the $200,000 price tag that went along with moving it. As Italia Peretti, Director of Development for Casey Trees put it:

> *"moving a tree has a huge price tag, about $200,000. It's worth it. Having this mature tree on your campus adds to value of the property, and you're doing a great thing for the city, showing that you care about what people have done."*

**2.3 Benefits of Urban Trees**

The benefits of trees are numerous and far reaching. Many studies have shown the benefits of planting trees to include natural processes for cooling, recreation, biodiversity conservation, groundwater recharge, reducing surface water runoff, reducing the urban heat island effect, improving air quality by intercepting various pollutants, sequestering carbon, enhancing public health, increasing property values, fostering economic development, reducing surface water runoff, conserving energy, improving air quality, reducing noise pollution, enhancing health, providing wildlife habitat, providing aesthetic benefits, and beautifying neighborhoods (McFarland 1994; Brack 2002; de Bries et al. 2003; Foster and Hillsdon 2004; McPherson et al. 2005, 2001a, b).

### 2.3.1 Urban Heat Island Effect

Many of the benefits of trees are related to their ability to offset environmental issues that arise in urban environments. For example, trees play a large role in offsetting the urban heat island effect.

> *"Urban heat island refers to the characteristic warming of urban areas compared to their rural surroundings as a result of changes of surface and atmospheric conditions from urbanizing (e.g. expansion of buildings, roads, pollution, or energy use). Urban heat island is an inadvertent climate change that arises from changes to surface radiation and energy balance and reduction of cooling rates in urban areas. This effect is attributed to the large expansion of non-evaporative, impervious material covering large urban areas which increases sensible heat flux and decreases latent heat flux," (Akbari, 2002; Pincetl, 2013).*

Research by Pincetl, et al. analyzed the effectiveness of Los Angeles' Million Tree Program. Part of this research looked into the impact of trees on the urban heat island. Using a combination of satellite derived tree cover, vegetation index, historic and digital aerial photography within LA since 1920 and surface temperature, the researchers were able to quantify the impact trees have on decreasing urban heat island effects by studying surface temperature changes that have resulted from tree cover and urbanization over the past 30 years. They found that over 60% of land surface temperature variations are explained by the percentage of city blocks that is shaded by trees. They also found that city blocks that had more than 30% tree cover are up to 5° Fahrenheit cooler than those with less than 1% tree cover. Additionally, they found that lawns had little to no impact on cooling, concluding that tree shade is what led to the cooling, rather than surface evapotranspiration. Studies by Saito, et al have reached similar conclusions, finding that maximum temperatures within the greenspace of individual buildings sites are up to 5° F cooler than outside the greenspaces. Other studies have found that temperature differences between dense urban areas and suburban areas can be more than 9° Fahrenheit (Mizuno, M., et al. 1990/91).

More and more, urban planners, residents, business owners, property owners, and others are turning to landscaping to offset the urban heat island effect as a means to increase comfort and decrease costs. The growth of U.S. urban areas over the past 50 years has been linked to a steady climb in urban temperatures, equaling approximately 1 ° Fahrenheit per decade (McPherson, et al. 1993). Studies have shown that electricity demands in US. Cities increases 1-2% per degree Fahrenheit increase in temperature. Therefore, to offset the warming urban environment, or the urban heat island effect, electricity demand has increased 3-8% (Akbari, H., et al. 1992). The costs associated with this increase in electricity demand are high, leading many people to look for alternatives such as strategic landscaping. When planted correctly, landscaping can lead to significant savings. For example, one study shows that shading from shrubs in trees in Florida and Pennsylvania resulted in cooling savings of 30 percent or greater through shading, evapotranspiration, and air flow modification (Parker, J.H, 1983).

### 2.3.2 Other benefits

As urban areas grow and develop, impermeable surfaces such as pavement and roofs increase, while permeable surfaces such as green spac

es, decrease.  This can increase the incidence and severity of flooding, and requires extensive infrastructure to retain stormwater run-off.  Often times, developers are required to build on-site detention basins for stormwater, which is a costly endeavor (McPherson, et al. 2005).  Based on costs of construction, land acquisition, and landscaping, a typical basin costs $.02 per gallon of capacity.  To use this metric as means to quantify to stormwater storage benefit of trees, McPherson, et al determined that the crown of the mature tree in Fresno was estimated to intercept 182 gallons of rainfall per year, with the annual implied value to be $3.64.

Trees have other benefits that are less easy to quantify, such as social benefits trees provide.  Some social benefits arise from tree-planting programs.  For example, tree planting programs play an important role in building our communities by creating jobs, healthier environments, a greater connection to nature, and positive community interactions (Dwyer, et al. 1992).

Trees provide tremendous health benefits.  They can be seen as acting like a sponge, soaking up impurities in the urban atmosphere like carbon dioxide and particulate matter.  Multiple studies found that vegetation adsorbs pollutants and, decreasing airborne gases and particulate matter in the atmosphere (Errell, 2008).  A mature urban tree can intercept up to 50 pounds of particulates per year, thus improving air quality (Dwyer, et al. 1992).  In turn, improved air quality will enhance physical and mental health which can have a secondary benefit of decreased healthcare costs.

The presence of urban trees and forests has been associated with decreased stress and improved physical health in urban residents (Dwyer, et al. 1992). In a very impressive study, it was found that hospital patients with window views of trees recovered significantly faster with few complications than comparable patients without these views (Ulrich, 1984).

As urban environments grow busier, and become "cities that never sleep," trees become an important barrier to sound, significantly cutting down noise. It has been found that "wide belts of tall dense trees combined with soft ground surfaces can reduce apparent loudness by 50% or more," (Cook, D.I. 1978).

Additionally, trees have actually been attributed with the ability to deter crime. The traditional thought is that vegetation makes crime easier, including a 2001 case study of auto thieves in Washington DC that found that "thieves often target areas near dense vegetation because it can reduce effort and risk by offering concealment," (Citylab, 2012). However, growing research is showing that trees can deter crime. One way they do this is by attracting more people to public places, putting more eyes on the street. Well cared for trees and landscaping also signifies to thieves and others that people care about their neighborhood, which results in the opposite effect of the Broken Window theory (Citylab, 2012). In a separate 2001 study of public housing in Chicago, it was concluded that "the greener a building's surroundings were, the fewer crimes reported." An associated article in an issue of Landscape and Urban Planning overviews research by Austin Troy and associates in Baltimore, who found there to be an inverse relationship between tree canopy and crime. They conclude that "a 10% increase in tree canopy was associated with a roughly 12% decrease in crime." The researchers carefully controlled for numerous factors known to influence crime statistics (income, race, population density, etc) and still came to the conclusion that more trees are associated with less crime. They found that tall broad canopies are specifically linked with reduced crime, while low, dense brush seemed to be associated with increased crime. Similar results were found in a 2012 study by the USDA in Portland, Oregon and reported that while tall trees are associated with decreased crime, lower bushes and shrubs and the like can actually increase crime (Donovan, 2012).

### 2.3.3 Existing cost benefit analyses

Using the various methods and metrics listed above, research by McPherson, et al (1993) has been able to perform simulations that conclude that a single 25 foot tall tree can reduce annual costs associated with heating and cooling by 8-12 percent ($10-$12) for a typical single family home (McPherson, et al. 1993). These quantities were estimated using a variety of sub-models for energy and carbon savings, air pollution interception/absorption, stormwater runoff reduction, salvage value, property value increases and other aesthetic, social, and ecological benefits. The study results show that the 30 year present value of benefits and costs per tree was $1,426 and $74, respectively. The 30 year present value of all trees was projected to be $22.3 million with benefit-cost ratio of 19.3 (McPherson, et al. 1993).

A separate study by McPherson et al. (2005), once again found benefits to greatly outweigh costs. Using STRATUM (Street Tree Resource Analysis Tool for Urban

Forest Managers) to estimate annual benefits and costs of trees, their study found that annual costs were $13-16 while annual benefits were $31-89 per tree. For this study, to calculate costs, the researchers gathered information on annual tree program expenditures between 2003 and 2005 as well as expenses related to sidewalk and curb repair, leaf cleanup, and trip and fall claims. Benefits were quantified using computer simulations, estimations, and direct valuation. Computer simulations were used to estimate energy savings based on building, climate, shading, and weather. Calculations of tree growth and biomass were used to estimate atmospheric carbon dioxide reductions. Air quality benefits were calculated based on deposition velocities for ozone, nitrogen dioxide, sulfur dioxide, and particulate matter and hourly meteorological data on pollutant concentrations. A model was used to estimate stormwater runoff reductions based on tree crown and root uptake. Further, stormwater reduction benefits were priced by estimating costs of controlling stormwater runoff, as was done in the researchers' earlier study. Additional "aesthetic and other benefits" that were taken into consideration were: aesthetics, beautification, privacy, wildlife habitat, sense of place, and well-being, and increase in property value.

Results of this study showed that "aesthetic and other benefits" accounted for the single greatest benefit, making up 59-75% of total annual benefits. This study also found that pruning was single greatest expenditure, making up 27-43% of total annual costs (McPherson, et al. 2005).

A thorough paper by USFS's extension campus further notes that the benefits of trees include "Increase property value, decrease energy costs, reduction in stormwater runoff, bioremediation, decrease in soil erosion, improvement in water quality, improvement in air quality, creation of wildlife habitat, increase in community pride, positive impact on consumer behavior, increase in recreational opportunities, improvement in health and well-being, reduction of noise levels, creation of buffer zones," (Macie, E.) This paper further details each of these benefits and compares findings to previous studies, concluding that benefits of trees can be up to three times greater than the costs. Many, many studies and reports further agree that the benefits outweigh the costs of trees, and come to similar conclusions as to what these benefits are and what these costs are. Most studies also come to the conclusion that the greatest benefits of trees are experienced when the proper tree is selected and planted in the proper location, a practice known as "right tree right place," (Macie, E.).

### 2.4 Costs of trees

The benefits of trees discussed above are far reaching and numerous, however, the monetary values associated with them are indirect. The costs of trees in the public rights of way, however, are direct and fall almost entirely on local municipalities.

An assessment of Los Angeles' One Million Tree program by McPherson, et al concluded that planting 1-million trees would yield up to $1.95 billion of benefit for the city over 35 years (McPherson, 2007). However, as Pincetl et al point out in a separate analysis of the same program, 81% of the quantified benefits were aesthetic, while only 8% were stormwater runoff reduction, 6% were energy savings, 4% were air quality improvement and less than 1% atmospheric carbon dioxide reduction (Pincetl et al, 2013).

In that same analysis, Pincetl et al. found that tree species are highly variable in their environmental costs and benefits, and treating the urban forest as a homogenous entity can lead to major errors in quantifying the net value of benefits provided by trees. This is especially true when the benefits are intangible, aesthetic benefits, while the costs are tangible, budget-constraining costs directly to the local municipality.

One of the common benefits of trees that is boasted is their capacity for carbon sequestration. However, research that took place in Los Angeles by Pincetl et al found that in order for trees to offset appreciable amounts of anthropogenic carbon dioxide, forests would need to be planted in areas much larger than possible in cities. Results from this study also call into question the ability of trees to increase property value. Research indicated that increases in parcel tree canopy cover will not typically increase the value of multifamily buildings, even though the residents would benefit from an increase in canopy cover. These results are contradictory to most published studies (Donovan and Butry 2010 or Sander et al. 2010), suggesting that property values do not uniformly increase in all cities as a result of increased canopy cover.

A commonly researched benefit of trees, as outlined in length above, is the ability to reduce energy consumption in buildings if planted in the correct areas. However, research by Errell (2008) points out:

> *"It should be noted in this context that heat transfer through building walls is driven by differences in surface temperature, rather than by air temperature. Furthermore, the reduction in air temperature resulting from evapotranspiration is accompanied by an increase in the vapor content of the air. Therefore, the air-conditioning system must deal with an increased latent heat load, offsetting to some extent, any gains from a lower sensible heat load."*

This research goes on to explain that while tree shade reduces the radiant heat load on a building, the effects are beneficial in warm climates however can be detrimental in cold climates and actually increase costs and energy used for heating the building. It is also noted that in temperate climates, "the timing of defoliation and the permeability of the bare trees vary widely from species to species," and can reduce the experienced benefits of trees. In warm climates, it is found that vegetation can reduce wind speed near buildings, limiting unwanted infiltration, but also "restricting ventilation and reducing convective exchange at building surfaces," (Errell, 2008). Wind is an asset for buildings, as it removes radiant heat from building surfaces (McPherson, et al. 1998). Therefore, it is possible that vegetation can have an adverse effect on buildings from what was found in other research.

Costs of trees are not as thoroughly researched as the benefits. The costs that are discussed in research include the costs of planting, establishing, and caring for trees, pruning, water and energy consumption, irrigation, pest and disease control, green waste disposal, health issues arising from pollen production, hydrocarbon emissions, displacement of native species, damage to infrastructure, and blocked solar collectors. A 2005 study by McPherson, et al calculates the costs of trees studied to range from $15-$65 per tree in a study of urban forestry. This study goes on to break down the costs, finding that pruning was most expensive, accounting for

25-40% of costs, followed by administration and inspection costs at 8-35% and the cost of tree planting accounted for just 2-15%.

One surprising report from the UK shows that trees can actually lead to detrimental health effects (Vidal, 2016). In this report, the National Institute for Health and Care Excellence in New Guidance for Local Governments to Combat Air Pollution says that, "leaves and branches can slow air currents and cause pollutants to settle," thereby actually trapping pollutants and ground level. Trees "may also act as sinks for particulates and chemicals that may have direct or indirect effects in air quality." The air quality under trees deteriorates at street level, as fumes from vehicles settle and get trapped, they say.

When thinking about the costs of trees in an urban environment, it is important to note that it is indeed an urban environment, as opposed to natural grown forests. This has impacts on the mortality of trees and associated maintenance costs. As one study points out, urban street and yard trees are typically produced by nurseries and planted in public right of way, surrounded by concrete (Roman, et al. 2016). Urban environments pose many challenges for trees, such as compacted and contaminated soil, construction, and vandalism. Trees in urban environments deter from their natural lifespan, growing patterns, and survival rate. This relationship to mortality means that costs associated with planting and establishing trees will be reoccurring, as tree life span may be shorter than predicted. There are also costs associated with removed dead or dying trees, which will also be reoccurring.

Costs associated with the above mentioned items are understood by most municipalities, though perhaps understated in the research. For example, damage to infrastructure due to tree roots can be extensive and expensive. Damage to sidewalks can lead to further costs associated with trip and fall lawsuits. These costs can be very high and need to be further researched and understood. Additional costs that are not fully explained in existing research are the costs associated with nutrient loading in waterways from tree leaves. Tree leaves decompose in waterways and increase the level of nutrients in the water, leading to water quality concerns, algae blooms, decreased dissolved oxygen, and more.

### 2.5 Who is experiencing benefits versus costs of urban trees

As stated previously, benefits of trees are largely intangible, indirect benefits experienced by a community at large. The direct costs, such as planting, maintenance, pest control, infrastructure repair, etc., fall on local government agencies. Further, as reported in an earlier study, when all benefits are computed, aesthetic benefits accounted for the single greatest benefit, making up 59-75% of total annual benefits. (McPherson, et al. 2005). Aesthetic benefits are arguably the most intangible benefit of all those discussed and monetized.

Trees and tree planting programs are indeed a public benefit and should continue to grow and expand in communities. However, as these programs grow and tree canopies expand, so do the costs. It is imperative that local governments understand and budget for these costs.

## 3. Research Question

1. What are the costs of trees with regards to stormwater management?

    a. What are the costs associated with the prevention of polluting waterways?

    b. What are the costs associated with the mitigation of polluted waterways?

2. How will the costs of urban trees increase as an urban canopy increases?

    a. How will stormwater maintenance costs increase as tree canopies increase in size? How can local governments prepare for the additional costs of a growing tree canopy?

## 4. Methodology

This thesis will research the costs of urban trees that are taken on by local governments. The specific focus will be costs that are related to stormwater management. As trees increase and a tree canopy expands, there will be significant costs that fall onto the stormwater management groups of local municipalities, largely due to the increased amount of leaves that fall from the trees. The increased amount of leaves will require a greater need for street sweeping as well as a long term need to restore water bodies that have become impaired by tree leaves entering local water bodies and contributing to increased nutrient levels in waterways. These specific items will be researched because current research does not fully define these costs.

Tree leaves contain high amounts of nutrients, primarily nitrogen and phosphorus. Tree leaves that go unswept, raked, or collected in some other manner, often enter local waterways via stormwater infrastructure. The leaves then release their nutrients into the water. Excess amounts of nitrogen and phosphorus in waterways can impair water bodies and lead to algal blooms, reduced oxygen levels, and more. If a waterway is impaired for nutrients, the local government is responsible for reducing the nutrient levels in the water.

If a waterway is impaired for nutrients like nitrogen and/or phosphorus, the local government can be subject to a Total Maximum Daily Load, or TMDL, or a Best Management Action Plan, or BMAP, being placed on the water way. This requires the local government to limit nutrients from the waterway until it meets acceptable limits set forth by the state and federal government. This is a costly and time consuming project. Costs of removal of nitrogen and phosphorus from waterways may come from increased street sweeping, changes to stormwater infrastructure, public outreach, water quality monitoring, etc.

To determine these costs, I will work closely with the City of Orlando to research costs incurred from trees by the Public Works department, specifically, the Streets and Stormwater Division of the City. I will gather an understanding of what costs are incurred by this department due to trees, and what actions are taken to prevent water quality impairment as well as mitigate existing impairment. I will also research what the current budget is for managing these things, and what is needed to continue to manage these items while the urban tree canopy in the City of Orlando expands. The City of Orlando is already dubbed a "Tree City, USA," and has further proclaimed to increase the urban tree canopy substantially in the future as a part of their sustainability program, as many other cities across the United States and world have done.

**Tree Canopy**

It will first be important to understand the existing tree canopy in the City of Orlando, and what percentage of the City is currently covered by trees. By working with the City of Orlando's Parks Division and using i-Tree software, the current size of Orlando's tree canopy will be defined. I-Tree Software is a widely used software package that analyzes tree canopies using GIS data. This information will be important to know, so that in the future, it can be determined how canopy growth actually relates to costs.

**Street Sweeping**

One portion of this research will include an analysis of the street sweeping operation at the City of Orlando. Many actions are taken to prevent tree leaves from entering water bodies. This includes education efforts to get residents to rake, bag, or compost leaves and prevent them from entering water bodies. Once leaves leave a property, the first effort to collect them is street sweeping. Any leaves that are not collected after street sweeping will go into a stormwater drain or flow overland to a waterbody. The leaves that go into the stormwater system may get caught up in an inlet basket, baffle box, or other pollution control device. However, once leaves enter the stormwater system, the practices to keep them out of the waterways become less effective and more expensive. Therefore, the critical time to collect leaves is before they enter the stormwater system, through street sweeping. For that reason, the street sweeping operation is what will be researched for the sake of this paper.

Street sweeping is the main method of preventing tree leaves and other tree materials (branches, seeds, bark, etc.) from entering waterways. Street sweeping also collects materials that are not tree material, however, the majority of debris collected by street sweepers is tree debris. In order to understand the costs associated with street sweeping, I will work with the City of Orlando and gather data on the street sweeping costs. These costs will include the cost of the street sweeper vehicles and related annual maintenance needs, as well as the wages for the employees operating the street sweepers. I will gather procurement data for the Stormwater Division to understand what costs are spent on Street Sweeping vehicles and maintenance. To determine the amount of money spent on wages, I will determine how many work hours were spent on the street sweeping operation as well as the average wage paid to employees.

**Water Body Restoration**

Once a body of water is deemed impaired and has a TMDL or BMAP placed on it, the local municipality must take action to restore that body of water. Each action taken gives the municipality "credits." Credits are measured in pounds of phosphorus and pounds of nitrogen loading removed from the waterbody. By determining the costs of removal per pound of phosphorus and per pound of nitrogen, the cost of leaves and other tree materials entering a water body can be extrapolated.

To find this number, I will first find the amount of money spent on various stormwater best management practices aimed to prevent or remove pollutants from waterways. I will then look at how many credits these various actions receive and how much phosphorus and nitrogen they keep out of waterbodies. With this information, I will be able to determine an average for what the City of Orlando is currently paying to keep or remove phosphorus and nitrogen out of lakes.

To quantify the cost of leaves entering water bodies, I will use a previous study on street sweeping in a nearby Florida City as well as established data from the Florida Stormwater Association. This data will tell what the average amount of nitrogen and phosphorus is in a pound of tree leaves. Using this number and the average cost to keep nitrogen and phosphorus out of lakes, I will be able to determine the cost of a pound of tree leaves entering a waterbody.

## 5. Results

Results are split into five sections. The first is the existing tree canopy coverage in the City of Orlando and what the percentage of tree cover is in the City. The second section is costs associated with street sweeping. The third is costs associated with restoring polluted waterways once they have already become impaired by nutrients. The fourth section analyzes the cost of tree leaves and debris (seeds, branches, bark, etc.) once they enter a waterway. The fifth section examines how costs will increase as urban tree canopies grow.

**Tree Canopy**

The existing canopy of trees in the City of Orlando was analyzed with i-Tree software by the City of Orlando's Parks Division. Appendix 4 shows all data found by this software. The percentage of tree coverage is based off of total area of the City minus land that is either airport or water. This is because trees will never grow in these areas. The total area of the City of Orlando is 118.53 square miles. Airports and water make up 27.3 square miles. Therefore, the total area of the City minus airports and water is 91.23 square miles. Based on i-Tree software that analyses based on GIS satellite data, trees make up a total of 29 square miles, or 32% of the total area of the City of Orlando, minus airports and water. According to a 2010 assessment by DeepRoot, a private research entity, the national average of tree canopy coverage in American cities is 27.1% (DeepRoot, 2010). This number was found using analyses similar to i-Tree software for various cities across the United States. According to this assessment, the City of Orlando is above average for tree canopy cover. However, the common recommendation for tree canopy cover in cities east of the Mississippi River is 40%, a number that many U.S. cities have adopted as a goal. Therefore, the City of Orlando is aiming to increase tree canopy cover by 8%, or another 7.3 square miles.

**Street Sweeping**

Prior to 2016, the City of Orlando leased street sweeping vehicles and paid maintenance costs through those leases. In 2015, the City purchased street sweepers and entered into agreements with contractors to maintain these vehicles. The data from 2016 and beyond will be looked at, once the City purchased the vehicles. The City of Orlando uses two contractors to handle maintenance of street sweepers, Pat's Pumps and Environmental Products of Florida. These companies are also who the City purchases vehicles from. The breakdown of the annual costs for each contract can be seen in Tables 1 and 2. Included in these costs are routine and major maintenance. Not included are the costs of street sweeping vehicles. Those costs are listed in Table 3. The totals for each year, including maintenance costs and vehicle costs, are listed in Table 4. It should be noted that costs were much higher in 2016 than the following years, because a high degree of maintenance was needed for the purchased vehicles. 2016 also includes the cost of the purchase of several vehicles. The average for total expenditures over the three years reported is an annual cost of $881,313.10.

| Year | Costs |
|---|---|
| 2016 | $46,160.96 |
| 2017 | $49,551.16 |
| 2018 | $64,899.59 |

**Table 1. Annual costs to Pat's Pumps**

| Year | Costs |
|---|---|
| 2016 | $592,924.09 |
| 2017 | $415,813.75 |
| 2018 | $305,601.15 |

**Table 2. Annual costs to Environmental Products of Florida**

| Year | Costs | Contractor |
|---|---|---|
| 2016 | $11,534.00 | Pat's Pumps |
| 2016 | $31,736.00 | Environ. Products of FL |
| 2016 | $434,102.00 | Environ. Products of FL |
| 2017 | $249,388.59 | Pat's Pumps |
| 2017 | $171,384.00 | Environ. Products of FL |
| 2018 | $270,844.00 | Pat's Pumps |

**Table 3. Costs of Purchasing Street Sweeping Vehicles**

| Year | Costs |
|---|---|
| 2016 | $1,116,457.05 |
| 2017 | $886,137.50 |
| 2018 | $641,344.74 |

**Table 4. Total costs for Street Sweeping Vehicles and Maintenance**

The second cost associated with street sweeping is that paid towards wages of employees operating the street sweepers. The City of Orlando currently has 10 full time employees dedicated to the street sweeping operation, 7 of these being daytime employees and 3 being nighttime employees. According to City of Orlando staff, the general number of work hours for a year for a full time employee is 2,080 hours. The average wage is $18.03 per hour. Therefore, the annual costs paid towards salaries of street sweeping per year is $375,024. It should be noted that this number does not include the costs that go towards benefits such as healthcare and retirement, as well as other employer-paid benefits. This amount, estimated by the City of Orlando, is approximately 75% of the amount paid towards salary. Adding this cost would add an additional $281,268 to the $375,024 being paid towards salaries, totaling $656,292 paid annually towards salaries of street sweeper operators.

The total average annual cost of the street sweeping operation in the City of Orlando, including the $881,313.10 for equipment and maintenance, as well as the $656,292 for salaries, is $1,537,605.10.

**Water Body Restoration**

The City of Orlando is currently subject to several Best Management Action Plans, or BMAPs, as well as Total Maximum Daily Loads, or TMDLs. This means that the State of Florida's Department of Environmental Protection is requiring the City to put plans into place to reduce nutrients loading of water bodies. A high quantity of these nutrients come from tree leaves that enter and decompose in water bodies through stormwater pipes or by being carried over the land via stormwater.

It is far easier and less expensive to prevent nutrients from entering water bodies than it is to remove them once they are in water bodies. Once a BMAP or TMDL is placed on a waterway, annual reports must be made to the Department of Environmental Protection to show what actions have been taken to prevent pollutants from entering waterways as well as what actions have done to remove nutrients from water bodies.

Appendix 1 shows what actions the City of Orlando is taking for all BMAPs and the costs related to each of those actions, as well as the effectiveness of those actions. This list includes ongoing actions, large projects, small projects, and projects that take place over several years. The list was last updated in 2018. Appendix 2 calculates the cost per pound of nitrogen removal and phosphorus removal for the same list. The average cost per pound of nitrogen removal is $19,762.32 and the cost per pound of phosphorus removal is $157,118.54. However, this list contains major infrastructure improvements that cost hundreds of thousands of dollars to millions of dollars. These costs are mostly for baffle boxes, exfiltration trenches, and retention ponds. Those high expenses skew the average to be much higher that it should be. For a more accurate number of the actual cost for removal of nitrogen and phosphorus, those large expenses were removed from the calculation to normalize the data. Appendix 3 shows the calculations that were used and the items that were averaged. After making the stated adjustments, the average cost per pound of nitrogen removal is $1,218.16 and the average cost per pound of phosphorus removal is $3,774.70.

**Cost of Leaves and Other Tree Debris**

A consultant group, GeoSyntec Consultants, performed a study to analyze street sweeping operations and effectiveness for the City of Lakeland, Florida, which neighbors the City of Orlando. In this study, street sweeping contents were analyzed to determine the levels of nutrients in the contents collected by the vehicles. This study separated out debris based on size and then analyzed the nutrients in each size category. Sieves were used to separate out the various sized groups, with 8 groups of sizes. The largest size group, 3/8 and ¾ inch, was almost completely tree debris, including acorns, seeds, branches, and predominantly, tree leaves. Laboratory analysis then determined the amount of nitrogen and phosphorus in the debris, measured in milligrams per kilogram dry material collected. Two samples were taken in commercial areas and two samples were taken in residential areas. Table 5 below shows the nutrient levels for the various samples of the large material. The average total nitrogen in debris collected in residential areas is 5,250mg/kg dry debris. The average nitrogen in debris collected in commercial areas is 6,050mg/kg dry debris. The average phosphorus in debris collected in residential areas is 940mg/kg dry debris. The average phosphorus in debris collected in commercial areas is 1,040mg/kg dry debris.

| | Residential Sample 1 | Residential Sample 2 | Commercial Sample 1 | Commercial Sample 2 |
|---|---|---|---|---|
| Total Nitrogen (mg/kg dry) | 4600 | 5900 | 6200 | 5900 |
| Total Nitrogen Average | 5250 | | 6050 | |
| Total Phosphorus (mg/kg dry) | 780 | 1100 | 1600 | 480 |
| Total Phosphorus Average | 940 | | 1040 | |

**Table 5. Nitrogen and Phosphorus Levels in Large Sized Debris**

Using the average cost per pound of removal of nutrients as well as the known amounts of nutrients in tree debris, it is estimated that one pound of tree debris in a residential area has an associated cost of $6.40 for nitrogen. One pound of tree debris in a commercial area has an associated cost of $7.37 for nitrogen. One pound of tree debris in a residential area has an associated cost of $3.55 for phosphorus. One pound of tree debris in a commercial area has an associated cost of $3.93 for phosphorus. Combined, this totals to $9.94 for a pound of tree debris in residential areas and $11.30 for a pound of tree debris in commercial areas.

**Cost Increases as Tree Canopy Expands**

According to the Geosyntec study, the 3/8 inch and ¾ inch material, which was analyzed above for nutrient content, makes up approximately 12% of all debris collected via street sweeping. This is a very conservative approach, as many of the smaller groups of materials consist of leaf particles, seeds, bark, and other tree material. The street sweeping operation in the City of Orlando collects approximately 2.7 million pounds, or 22,325 cubic yards, of debris each year. Applying the 12% rate to the total debris collected, trees are responsible for approximately 324,000 pounds, or 2,679 cubic yards, of debris landing on roadways annually. It should be noted that in actuality, this number would be much higher, since street sweeping does not collect all debris and many leaves and other tree debris end up in the stormwater system and subsequently into waterways.

Using the very conservative numbers calculated above, Orlando's 32% tree canopy, equal to 29 square miles, produces approximate 324,000 pounds, or 2,679 cubic yards, of debris on roadways annually. As stated above, the street sweeping operation is currently costing Orlando $1,537,605.10. That is approximately $48,050 for each percentage point of tree canopy cover, or $53,021 per square mile of tree cover. Therefore, for each increase in percent of tree canopy cover, an additional $48,050 should be budgeted towards the City's street sweeping operation. To reach the goal of 40% tree canopy coverage, the City of Orlando would need to increase its annual budget by 8%, or $384,400. Based on the timing of the tree canopy expansion, each year's budget would need to be determined based on the projected increase in tree canopy for that year.

The very conservative estimation of leaf fall on city streets in the City of Orlando can also be paired with the estimated cost associated with phosphorus and nitrogen loading to City lakes via leaves and other tree debris. Using the calculated numbers per pound of nitrogen and phosphorus, 324,000 pounds of tree debris on city streets would cost $3,220,560 in residential areas and $3,661,200 in commercial areas. Broken down per percentage point, this would equal $100,642.50 in residential areas and $114,412.50 in commercial areas. Therefore, for each percent increase in tree canopy, the annual budget would have to be increased by the appropriate amount to account for water quality remediation.

The numbers used for these calculations are an estimate. 324,000 was a conservative estimate for tree debris that is collected by street sweepers citywide. Since this is the amount that is collected and properly disposed of, it obviously is not the amount that is ending up in lakes. However, there is no reliable way to determine how much debris is actually making its way into City lakes. There is no universal number for the efficiency rate of street sweeping, since there can be so many variables. It can only be said that leaves and other tree debris are currently entering lakes and loading nutrients into the water, and as the tree canopy increases, the amount of tree-sourced nutrients entering lakes will increase at a rate similar to amount of leaves landing on streets.

## 6. Discussion

As more people move to urban areas, and local municipalities face the immediate challenges of climate change, it is important to have a plan and program to expand the urban tree canopy. Trees provide benefits that are far reaching and necessary. Cost benefit analyses will time and time again point to the benefits of trees outweighing the costs. However, many benefits are intangible and secondary to the local government, while the costs are direct dollar values hitting the budgets of local governments. Benefits, as summarized in the literature review of this paper, include savings in energy, provision of habitat, carbon sequestration, sense of community, beautification, better quality of life, improved mental health, decreased stress, and more. These are essentially public goods that trees provide, and are shared among the community. The costs of trees, as outlined in the literature review, can include maintenance, irrigation, planting, removal, litigation, and more. These costs are all those that fall on the local government and are often predicted, whether or not they are properly prepared and budgeted for. A main purpose of government is to provide public goods and services, so it makes sense that government can and should pay the costs that are associated with trees, so many can benefit. However, these costs still must be appropriately budgeted for. One area where current research is lacking is the costs of trees on local waterways.

The costs associated with stormwater maintenance incurred by adding trees to an urban canopy are often overlooked when planning for trees. Trees have a significant impact on local waterways that is overlooked in many previous research papers. The lack of research in this area reinforces that these costs are overlooked, unplanned for, and unbudgeted for. The additional costs incurred are costs that must be budgeted for in order for a tree planting program to be successful.

This research is not intended to dissuade local governments from planting trees. It is instead intended to be a guide for how to prepare for and budget for increasing an urban canopy. Trees no doubt are a benefit to humans, animals, and the environment at large. The benefits described in the literature review of this paper show that there are endless reasons to plant trees. However, as local governments implement programs to plant more trees, it is imperative to have a plan in place to budget for the expenses that come from trees.

This research analyzed two areas where trees are costing governments: the prevention of tree leaves and debris entering waterways via street sweeping, as well as the long-term costs to restore waterbodies that have been impaired by excess amounts of tree leaves. This research found that current trees are costing the City of Orlando's Streets and Stormwater Division approximately $1,537,605.10 annually in labor and equipment. Additional costs are the costs of nitrogen loading and phosphorus loading in waterways that results from tree leaves. This cost is $9.94 per pound of tree debris in residential areas and $11.30 per pound of tree debris in commercial areas, which adds up quickly as one tree can deposit thousands of pounds of leaves. As the urban canopy grows, it is expected that these costs will increase. These are important costs that need to be budgeted for and addressed early on in planning for a tree canopy expansion.

As the City of Orlando expands its tree canopy from the existing 32% to 40%, each additional percentage increase will cost an additional annual amount of $48,050 for street sweeping efforts. Because street sweeping is not 100% effective and many leaves and debris will still end up in waterbodies, each additional percentage increase of tree canopy will cost an annual estimate of $100,642.50 in residential areas and $114,412.50 in commercial areas for water quality remediation. The City of Orlando should estimate the approximate amount of trees it is planting each year, and use the above numbers to estimate the needed increase to the annual budget. It is predicted that an 8% increase in tree canopy will cost $1,299,700 annually to the City of Orlando. To compare, the 2018-2019 budget for Orlando for the General Fund was $488,421,658. Of that, $11,824,288 was allocated to Public Works, which houses the Streets and Stormwater Division. The Stormwater Utility Fund brings in an additional $24,950,399, on top of what is existing in the General Fund. This comparison shows that the annual cost increases are significant compared to the annual budget, and cannot be ignored.

It is important to note that cost increases, while on average may be linear, will not be linear on a year-by-year basis. This is because as street sweeping needs increase and infrastructure is needed to be installed, costs will come in large amounts and will have more of a step function. For example, if the City of Orlando needs to purchase a new street sweeper, this may not be covered by just a 1% increase in that year's budget.  Therefore, it will be important to predict what costs may be coming up in the coming year, so that the budget is adjusted accordingly.

This research shows that there are real costs associated with urban tree canopies, and these costs will increase as canopies increase.  This is true for the City of Orlando as well as other cities that wish to increase their tree canopy.  If each percentage of increase in tree canopy costs $162,462.50, and each square mile of increase would equal $147,231.64, the cost increase per tree can be estimated.  A mature forest has an estimated 100 trees per acre, or 64,000 trees per square mile. Therefore, one tree would cost approximately $2.30 for street sweeping needs and water quality mitigation.  This can be compared to the earlier cost benefit analysis by McPherson et al, which estimated annual benefits to be $31-89 per tree and costs to be $13-16 per tree.  Comparatively, the additional costs discussed here would be a substantial increase per tree, given costs estimated by prior research.

While no two cities have the same tree inventory nor are any two trees the same, the research here can be used as a rough estimate or framework to determine the cost of adding trees to other cities, based on existing tree canopy and desired increase to that canopy.  A full list of study limitations can be found in Appendix 6. There are many variables at hand that other cities should take into consideration for determining their own budget increase.  These include:  cost of current street sweeping program; efficiency of current street sweeping program; nutrient content in debris collected; state and federal requirements for remediating impaired water bodies; current tree canopy composition; desired increase to tree canopy coverage.

The costs discussed in this research are an extremely conservative amount. Additional costs incurred by other branches within government include those associated with tree maintenance and watering; repair of cracked sidewalks, curbs and roadways; repair to pipes that have been cracked by tree root intrusion; litigation over trip and fall cases; removal of tree debris removal; and more. A full list of additional costs can be found in Appendix 5.

It should be noted that there are ways to cut down on the costs of leaves and tree debris. The main way to cut costs is to educate individuals on proper planting and care/maintenance of trees. If private property owners are educated to rake, bag, mulch, or compost the leaves from the trees on their private property or the adjacent public right of way, these leaves would never even enter public right of way, would not need to be swept, and would not end up in water bodies. Education can also cut costs by informing individuals of "right tree, right place" planting ideology. This means, very plainly, plant the right tree in the right place. If a tree is known to grow very large with intrusive roots and large canopies, do not plant it in a small area between road and sidewalk. There are many resources available that inform individuals which species of trees are correct for certain areas, what each tree needs to grow (sunlight, shade, space, height, breadth, nutrients etc.), what species will work in some areas and not others, etc. Additionally, this research assumed that existing technology is what will be used as tree canopies increase. It is possible that better technology that is more efficient and cost effective could be used in the future, which could potentially cut costs dramatically.

## 7. Policy recommendations

Cities that are looking to expand their urban tree canopy, like the City of Orlando, should have a clear plan in place for that expansion. Strategic planning is of utmost importance for a successful tree canopy expansion. It should be understood what trees are being planted by the City versus private entity or individual, if trees are planted on public right of way or private property, who will be maintaining trees, and which species of trees are best for differing areas.

A major component of a tree expansion plan should include education. The first part of this educational component should be "right tree, right place." Individuals should understand what species of tree should be planted in a specific area. This information is easy to find, and most State extension campuses should have this information readily available. Ensuring that appropriate trees are planted in desirable areas for that tree ensures the tree's health, as well as decreases likelihood for that tree to cause interference with overhead and underground infrastructure, as well as sidewalks and roadways. For this reason, public tree giveaways should be done with caution, as many individuals may not follow "right tree, right place" methods. City planners and arborists should also use these same "right tree, right place" rules when choosing trees for public areas. The second educational component is to inform the public of the importance of retaining as much tree debris and leaves on property as possible and to take every action to keep that debris out of the public roadways. If leaves are raked and bagged, composted, mulched, etc., they will not enter the public roadway, they will not need to be collected by street sweepers, and they will not end up in a water body. Tree debris and leaves that are not collected on property will end up in the roadway and will need to be collected via street sweeper. This is where costs begin to accrue.

Inevitably, leaves will be missed by street sweepers and will enter stormwater systems and subsequently waterways. After leaves enter the stormwater system, various types of infrastructure can be put in place to collect them, however, these methods increase drastically in cost and decrease in effectiveness. Costs will then inevitably accrue as leaves enter water bodies and impair the water. Therefore, it is most cost effective to minimize the leaves that are entering public roads through education.

Because leaves will undeniably enter the public road, it is also important for policy makers and city planners to understand the costs associated with urban trees and the appropriate budgetary needs that will come up as increased street sweeping and water quality remediation costs increase. A sustainable source for funding these increased budgetary needs should be identified as a part of the tree canopy expansion plan. The budgetary needs related to leaf collection and water quality will be ongoing and will continue to increase, as trees continue to grow. Many cities require permits to remove trees; the funds collected from these permits can and should go towards tree planting programs and the associated costs. However, that may not be enough funding to cover all costs. Other sources of funding should be identified to ensure the additional costs of street sweeping and water remediation.

A policy recommendation that would provide a source of funds as well as deter leaves from entering the streets and stormwater system would be to adopt a code that makes blowing leaves into the street or storm drains an illegal and finable offense. Many municipalities, like the City of Orlando, have stormwater sections of their code that does make this action illegal. If enforcement of this is increased, fines collected could go towards the stormwater-specific costs of increasing an urban tree canopy. In addition, heavy and steady enforcement of these actions will in the long run deter people from blowing leaves into the street and stormwater system, which is a major source of nutrients to the stormwater system.

Another source of funding for the increased costs of an expanding urban tree canopy would be the stormwater utility fee. Many cities and municipalities have stormwater fees that are paid for by property owners, and go towards the budget of the stormwater division of the municipality. If this fee is increased, even nominally, it would provide the needed funds to cover the stormwater-specific costs of an expanding tree canopy.

A strategic tree canopy expansion plan should also include a timeline. Tree canopies should be increased cautiously and strategically. Once trees are planted, they will only get bigger and costs will only increase. It should be understood what the future projected costs are 1, 5, 10, 50 years down the road for a tree that is planted today.

## 8. Conclusion

While there are many benefits to trees, there are also costs. Most of these costs are understood and planned for when expanding a tree canopy. However, the costs associated with tree debris and leaf collection as well as water quality impact was previously missing from current research. When planning for a tree canopy expansion, cities should plan for a slow and steady increase in tree canopy over a defined period of time. The expansion should be done systematically, strategically, and decisively. Trees are a major public benefit, and government should provide that public good and service. Trees provide health, environmental, and aesthetic benefits, as well as the benefits of avoided energy costs, and much more. These benefits are incredibly impactful and truly provide a public good. It is important to expand urban tree canopies and preserve existing trees. However, it is important to understand what the short term and long term costs of this will be. Municipalities should be careful to expand only much and as quickly as they can budget for. This research is by no means meant to dissuade municipalities from planting trees; it is meant only to provide a missing piece of the puzzle, and make municipalities aware of costs that are associated with trees so they can properly budget and successfully increase their urban tree canopies.

## Appendix 1. City of Orlando actions towards BMAPS

| ProjectType | TNReduction (lbs/yr) | TPReduction (lbs/yr) | Cost | CostAnnualO&M | FundingAmount |
|---|---|---|---|---|---|
| BMP Cleanout | 2 | 1 | N/A | Not provided | N/A |
| Street Sweeping | 119 | 90 | N/A | Not provided | N/A |
| Education Efforts | 17 | 2 | $51,500 | Not provided | Not provided |
| Alum Injection Systems | 5 | 1 | TBD | $9,141 | $291,323 |
| BMP Cleanout | 4 | 3 | N/A | Not provided | N/A |
| Baffle Boxes-Second Generation | 0 | 0 | TBD | Not provided | $259,560 |
| Baffle Boxes-Second Generation | N/A | N/A | N/A | N/A | N/A |
| Catch Basin Inserts/Inlet Filter Cleanout | 35 | 22 | $48,826 | $3,566 | Not provided |
| Wet Detention Pond | 37 | 1 | $1,239,249 | Not provided | City - $948,249 DEP - $291,000 |
| Catch Basin Inserts/Inlet Filter Cleanout | 68 | 42 | $40,480 | $11,735 | Not provided |
| Catch Basin Inserts/Inlet Filter Cleanout | 51 | 31 | $17,755 | $8,673 | Not provided |
| Catch Basin Inserts/Inlet Filter Cleanout | 33 | 20 | $8,550 | $9,706 | Not provided |

| | | | | | |
|---|---|---|---|---|---|
| Catch Basin Inserts/Inlet Filter Cleanout | 22 | 13 | $8,550 | $11,451 | Not provided |
| Catch Basin Inserts/Inlet Filter Cleanout | 55 | 33 | $17,755 | $7,049 | Not provided |
| Street Sweeping | 18,477 | 28,817 | Not provided | $850,000 | $850,000 |
| Education Efforts | 7,584 | 456 | $51,500 | Not provided | Not provided |
| Catch Basin Inserts/Inlet Filter Cleanout | 40 | 24 | $8,550 | $8,332 | Not provided |
| Baffle Boxes-Second Generation | 3 | 1 | $578,138 | Not provided | City - $289,069 SFWMD - $289,069 |
| Baffle Boxes-Second Generation | 2 | 1 | Part of project ORL-1 | Not provided | Part of project ORL-1 |
| Baffle Boxes-Second Generation | 6 | 1 | $942,710 | Not provided | City - $471,355 DEP - $471,355 |
| Wastewater Service Area Expansion | Not provided | Not provided | $3,522,911 | Not provided | Not provided |
| Baffle Boxes-Second Generation | 44 | 18 | Part of ORL-4 | Not provided | Not provided |
| Wet Detention Pond | 265 | Not provided | $9,000,000 | Not provided | Not provided |
| Exfiltration Trench | 6 | 3 | $30,000 | Not provided | Not provided |
| Muck Removal/Restoration Dredging | Not provided | Not provided | $20,000 | Not provided | Not provided |

| | | | | | |
|---|---|---|---|---|---|
| Sanitary Sewer and Wastewater Treatment Facility (WWTF) Maintenance | Not provided | Not provided | $2,000,000 | Not provided | Not provided |
| Street Sweeping | 6,312 | 4,048 | Not provided | Not provided | Not provided |
| Study | N/A | N/A | $49,900 | N/A | Not provided |
| Wastewater Service Area Expansion | Not provided | Not provided | $53,977 | Not provided | Not provided |
| Sanitary Sewer and Wastewater Treatment Facility (WWTF) Maintenance | Not provided | Not provided | $1,400,000 | Not provided | Not provided |
| Wastewater Service Area Expansion | Not provided | Not provided | $1,622,124 | Not provided | Not provided |
| Wastewater Service Area Expansion | Not provided | Not provided | N/A | Not provided | Not provided |
| Hydrodynamic Separators | Not provided | 19 | $565,702 | Not provided | Not provided |
| Sanitary Sewer and Wastewater Treatment Facility (WWTF) Maintenance | Not provided | Not provided | N/A | Not provided | Not provided |

| | | | | | |
|---|---|---|---|---|---|
| Sanitary Sewer and Wastewater Treatment Facility (WWTF) Maintenance | Not provided | Not provided | $878,400 | Not provided | Not provided |
| Wastewater Service Area Expansion | Not provided | Not provided | Not provided | Not provided | Not provided |
| Catch Basin Inserts/Inlet Filter Cleanout | 10 | 6 | $3,000 | Not provided | Not provided |
| Catch Basin Inserts/Inlet Filter Cleanout | 17 | 10 | $2,250 | Not provided | Not provided |
| Baffle Boxes- First Generation (hydrodynamic separator) | 27 | 11 | $7,800 | Not provided | Not provided |
| Catch Basin Inserts/Inlet Filter Cleanout | 0 | 3 | $1,500 | Not provided | Not provided |
| Stormwater System Rehabilitation | N/A | N/A | Not provided | Not provided | Not provided |
| Stormwater System Rehabilitation | N/A | N/A | Not provided | Not provided | Not provided |
| Sanitary Sewer and Wastewater Treatment Facility (WWTF) Maintenance | Not provided | Not provided | Not provided | Not provided | Not provided |

| | | | | | |
|---|---|---|---|---|---|
| Sanitary Sewer and Wastewater Treatment Facility (WWTF) Maintenance | Not provided | Not provided | $300,000 | Not provided | $300,000 |
| WWTF Upgrade | Not provided | Not provided | $1,500,000 | Not provided | $1,500,000 |
| Baffle Boxes-Second Generation with Media | 24 | 3 | $800,000 | Not provided | $800,000 |
| Baffle Boxes-Second Generation with Media | 162 | 25 | $450,000 | Not provided | $450,000 |
| WWTF Upgrade | Not provided | Not provided | $6,000,000 | Not provided | $6,000,000 |
| WWTF Nutrient Reduction | 69,436 | Not provided | $12,500,000 | Not provided | $11,700,000 |
| Stormwater BMP Inspections | N/A | N/A | Not provided | Not provided | Not provided |
| Stormwater BMP Inspections | N/A | N/A | Not provided | Not provided | Not provided |
| Catch Basin Inserts | 0 | 2 | $1,500 | Not provided | Not provided |
| Catch Basin Inserts | 11 | 45 | $7,770 | Not provided | Not provided |
| Street Sweeping | 23 | 98 | Not provided | Not provided | Not provided |
| Study | N/A | N/A | $49,900 | N/A | Not provided |

| | | | | | |
|---|---|---|---|---|---|
| Sanitary Sewer Collection System Rehabilitation, Maintenance, or Replacement | Not provided | Not provided | $4,522,401 | Not provided | Not provided |
| Sanitary Sewer Collection System Rehabilitation, Maintenance, or Replacement | Not provided | Not provided | $767,632 | Not provided | Not provided |
| Sanitary Sewer Collection System Rehabilitation, Maintenance, or Replacement | Not provided | Not provided | N/A | Not provided | Not provided |
| Study | N/A | N/A | $112,000 | N/A | $112,000 |
| Regulations, Ordinances, and Guidelines | 353 | N/A | Not provided | Not provided | Not provided |

## Appendix 2. Costs Per Pound of Nitrogen and Phosphorus Reduction

| ProjectType | TNReduction (lbs/yr) | TPReduction (lbs/yr) | Cost | Cost Annual O&M | $/lb of N | $/lb of P |
|---|---|---|---|---|---|---|
| Education Efforts | 17 | 2 | $51,500 | Not provided | $3,047.34 | $32,187.50 |
| Alum Injection Systems | 5 | 1 | TBD | $9,141 | $1,865.51 | $8,310 |
| Catch Basin Inserts/Inlet Filter Cleanout | 35 | 22 | $48,826 | $3,566 | 1485.287004 | 2376.459206 |
| Wet Detention Pond | 37 | 1 | $1,239,249 | Not provided | $33,862.25 | $1,124,226.54 |
| Catch Basin Inserts/Inlet Filter Cleanout | 68 | 42 | $40,480 | $11,735 | 764.00988 | 1246.542436 |
| Catch Basin Inserts/Inlet Filter Cleanout | 51 | 31 | $17,755 | $8,673 | 521.1969294 | 856.2520983 |
| Catch Basin Inserts/Inlet Filter Cleanout | 33 | 20 | $8,550 | $9,706 | 552.0517035 | 920.0861724 |
| Catch Basin Inserts/Inlet Filter Cleanout | 22 | 13 | $8,550 | $11,451 | 907.2293592 | 1512.048932 |
| Catch Basin Inserts/Inlet Filter Cleanout | 55 | 33 | $17,755 | $7,049 | 450.0358387 | 750.0597312 |
| Street Sweeping | 18,477 | 28,817 | Not provided | $850,000 | $46.00 | $29.50 |
| Education Efforts | 7,584 | 456 | $51,500 | Not provided | $6.79 | $113.01 |
| Catch Basin Inserts/Inlet Filter Cleanout | 40 | 24 | $8,550 | $8,332 | 425.4188969 | 696.1400131 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Baffle Boxes-Second Generation | 3 | 1 | $578,138 | Not provided | $192,712.67 | $578,138 |
| Baffle Boxes-Second Generation | 6 | 1 | $942,710 | Not provided | $152,716.33 | $1,425,352.38 |
| Exfiltration Trench | 6 | 3 | $30,000 | Not provided | $5,000 | $10,000 |
| Catch Basin Inserts/Inlet Filter Cleanout | 10 | 6 | $3,000 | Not provided | $300 | $500 |
| Catch Basin Inserts/Inlet Filter Cleanout | 17 | 10 | $2,250 | Not provided | $132 | $225 |
| Baffle Boxes-First Generation (hydrodynamic separator) | 27 | 11 | $7,800 | Not provided | $289 | $709 |
| Catch Basin Inserts/Inlet Filter Cleanout | 0 | 3 | $1,500 | Not provided | $3,295 | $500 |
| Baffle Boxes-Second Generation with Media | 24 | 3 | $800,000 | Not provided | $32,921.81 | $250,000 |
| Baffle Boxes-Second Generation with Media | 162 | 25 | $450,000 | Not provided | $2,778.50 | $17,787 |
| Catch Basin Inserts | 11 | 45 | $7,770 | Not provided | $692.01 | $172.67 |
| | | | | **Average $/lb** | **$19,762.32** | **$157,118.54** |

## Appendix 3. Cost Per Pound Nitrogen and Phosphorus Reduction–Normalized

| ProjectType | TNReduction (lbs/yr) | TPReduction (lbs/yr) | Cost | Cost Annual O&M | $/lb of N | $/lb of P |
|---|---|---|---|---|---|---|
| Education Efforts | 17 | 2 | $51,500 | Not provided | $3,047.34 | $32,187.50 |
| Alum Injection Systems | 5 | 1 | TBD | $9,141 | $1,865.51 | $8,310 |
| Catch Basin Inserts/Inlet Filter Cleanout | 35 | 22 | $48,826 | $3,566 | 1485.287004 | 2376.459206 |
| Catch Basin Inserts/Inlet Filter Cleanout | 68 | 42 | $40,480 | $11,735 | 764.00988 | 1246.542436 |
| Catch Basin Inserts/Inlet Filter Cleanout | 51 | 31 | $17,755 | $8,673 | 521.1969294 | 856.2520983 |
| Catch Basin Inserts/Inlet Filter Cleanout | 33 | 20 | $8,550 | $9,706 | 552.0517035 | 920.0861724 |
| Catch Basin Inserts/Inlet Filter Cleanout | 22 | 13 | $8,550 | $11,451 | 907.2293592 | 1512.048932 |
| Catch Basin Inserts/Inlet Filter Cleanout | 55 | 33 | $17,755 | $7,049 | 450.0358387 | 750.0597312 |
| Street Sweeping | 18,477 | 28,817 | Not provided | $850,000 | $46.00 | $29.50 |
| Education Efforts | 7,584 | 456 | $51,500 | Not provided | $6.79 | $113.01 |
| Catch Basin Inserts/Inlet Filter Cleanout | 40 | 24 | $8,550 | $8,332 | 425.4188969 | 696.1400131 |
| Exfiltration Trench | 6 | 3 | $30,000 | Not provided | $5,000 | $10,000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Catch Basin Inserts/Inlet Filter Cleanout | 10 | 6 | $3,000 | Not provided | $300 | $500 |
| Catch Basin Inserts/Inlet Filter Cleanout | 17 | 10 | $2,250 | Not provided | $132 | $225 |
| Catch Basin Inserts/Inlet Filter Cleanout | 0 | 3 | $1,500 | Not provided | $3,295 | $500 |
| Catch Basin Inserts | 11 | 45 | $7,770 | Not provided | $692.01 | $172.67 |
| | | | | **Average** | **$1,218.16** | **$3,774.70** |

## Appendix 4. Tree Canopy Analysis of the City of Orlando

| | Tree Canopy | Bare Ground | Buildings | Grass | Impervious Other | Road | Shrubs | Sidewalks | Total Area Minus Airports and Water (SqMi) | Water (SqMi) | Airports (SqMi) | Total Area of City (SqMi) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Percent of coverage | 32% | 3% | 11% | 27% | 12% | 9% | 5% | 1% | 100% | | | |
| Area Square Miles | 29 | 2.84 | 9.77 | 25 | 11 | 7.98 | 4.49 | 1.15 | 91.28 | 8.52 | 18.78 | 118.53 |

## Appendix 5. Additional costs on municipalities due to trees

There are many areas where trees lead to direct costs on municipalities. While this thesis explored only the costs related to stormwater management, the list of costs include many other items, the most common of which are listed below.

Direct costs of trees on municipalities:

1. Tree planting programs – programs to distribute trees to public, plant trees in public and private areas, care for and maintain trees, educate the public, etc.
2. Maintenance – trimming, pruning, irrigation, removal of trees in public areas
3. Underground infrastructure repair – repair of wastewater pipes, stormwater pipes, electrical conduit, potable water lines, etc. due to tree root intrusion
4. Aboveground infrastructure repair – repair of pavement and brick roads, sidewalks, building foundations, parking lots, etc. from tree root intrusion
5. Litigation – largely due to trip and fall law suits because tree roots lifted sidewalk panels, leading to trip hazard
6. Debris cleanup, typical – typical weekly collection of leaves, branches, and other landscaping debris by local solid waste collection agency
7. Debris cleanup, atypical – debris cleanup required following a natural disaster, such as a hurricane, tornado, extreme winds, floods, etc.

**Appendix 6. Limitations**

As any study goes, this study has limitations. The first set of limitations is the regarding the cost associated with the street sweeping operation. The City of Orlando hires full time employees for their street sweeping operations. The average wage used for the City of Orlando will likely vary from other municipalities. Additionally, other municipalities may not hire full time employees who receive benefits. If other municipalities are contracting out this work, they would not have to pay the additional amount assumed to go towards benefits. In this study, that amount was assumed to be 75% of the employee's salary. Along those same lines, contracts with street sweeping vehicle providers vary widely and may amount to a different cost for vehicles and maintenance. Additionally, it should be noted that the City of Orlando typically limits street sweeping services to curbed roads. Therefore, leaves that fall on non-curbed streets go entirely unswept, and are more likely to end up in the stormwater system and water bodies. The proportion of streets that are swept versus not swept (curbed versus non-curbed) could impact the cost related to street sweeping and the effectiveness of this operation.

The second set of limitations are those associated with the cost of removal of nitrogen and phosphorus from a body of water. The data used in this study was based off of the costs associated with the actions Orlando is currently taking to remove these chemicals from water or prevent it from entering body of water, and the associated effectiveness of these actions. It is possible that the effectiveness of these actions will vary in other municipalities, as well as the actions taken themselves. For example, municipalities may use different types of infrastructure with varying degrees of nutrient removal capabilities and associated costs.

The third set of limitations is related to the estimated nutrient content of leaves. The trees analyzed for nutrient content in this study are specific to Central Florida, where the predominant tree species is Oak. Therefore, data used in this study should be used cautiously in areas where trees vary. The nutrient content of leaves and tree debris likely will vary based on tree species.

Additionally, this study assumed that 12% of debris collected is directly related to trees. This is an extremely conservative number, as a much larger percentage of debris is from tree leaves, bark, seeds, twigs, etc. This percentage should be used knowing that it is an absolute minimum for an area like Orlando, which has a 32% canopy cover. In an area that does not have many trees, that percentage will likely change. In an area that is more densely covered in trees, that percentage will likely be greater.

This study found that 324,000 pounds of tree leaves are collected annually via street sweeping. This same number was used to calculate the cost associated with nitrogen and phosphorus loading in water ways by tree debris. The amount collected via street sweeping obviously would not be the amount that is ending up in lakes and therefore nutrient loading the water. However, the efficiency of street sweeping varies greatly depending on frequency of sweeping, time of year, miles swept, vehicle used, and more. Therefore, it is difficult to estimate how many leaves are making their way into water bodies. Using the same number for both what is collected via street sweeping and what is entering water bodies is a very conservative approach. Of the amount of leaves that ends up on roadways, close to 10% is actually collected by street sweepers. Another 10-25% may be collected via infrastructure like inlet baskets, baffle boxes, etc. The rest, however, will end up in waterways. This means that a much greater content is ending up in waterways than what is collected via street sweeping. Therefore, the costs provided in this research should be used as absolute minimums, since the approach to find them is tremendously conservative.

Another limitation to this study is the method used to calculate the increase in cost for future tree canopy expansion. The methods used in this study calculated the cost per percentage of tree canopy, and assumed that increases in cost would be linear. It was assumed that an 8% increase in canopy will essentially result in an 8% increase in cost. The relationship between cost and canopy size may vary, and likely is not perfectly linear. Future research should study this relationship, and how costs change as tree canopies increase.

## References


Akbari, H., D. Kurn, el al. 1997. Peak power and cooling energy savings of shade trees. Energy and buildings 25: 139-148

Akbari, H. 2002. Shade trees reduce building energy use and CO2 emissions from powerplants. Environmental Pollution, 116, S119-S126.

Akbari, H., Davis, S., Dorsano, S., Huang, J., and Winnett, S. (Eds.) 1992. Cooling our communities: a guidebook on tree planting and light-colored surfacing. Washington D.C. U.S. Environmental Protection Agency.

Anderson, L.M. and H.K. Cordell. 1985. Resdential property values improve by landscaping with trees. S. J. Appl. For. 9:162-166

Citylab. Equity. 2012. 05. Can trees actually deter crime.

Cohen, S. E. (2004). Nature, trees and the manipulation of environmental stewardship in America. Berkeley: University of California Press.

DeepRoot. 2010. Tree Cover % -- How Does Your City Measure Up? Blog [http://www.deeproot.com/blog/blog-entries/tree-cover-how-does-your-city-measure-up]

Dwyer, J., McPherson, G., Schroeder, H., Rowntree, R. 1992. Assessing the benefits and costs of the urban forest. Journal of Arboriculture 18(5)

Energy Information Administration. 1993. Household energy consumption and expenditures, 1990. Washington, DC: U.S. Department of Energy, Energy Information Administration.

EPA. 2017. Urban trees and vegetation to reduce heat islands. Heat islands. EPA. 2017.

Erell, E. Advances in building energy research. 2008. The application of urban climate research in the design on cities. Volume 2. Pages 95-121.

Geosyntec Consultants. 2017. Street Sweeping and Maintenance BMP Optimization Study. Pages 8-1 through 8-64.

Hagerty, K. 2019. Urban design meets forestry: heritage tree laws in motion at former Fannie Mae headquarters. Costar.

Huang, J., H. Akbari, and H. Taha. 1990. The wind-shielding and shading effects of trees on residential heating and cooling requirements. ASHRAE Winter Meeting, American Society of Heating, Refrigerating and Air-Conditioning Engineers. Atlanta, Georgia

i-Tree Ecosystem Analysis: Washington, D.C., Urban Forest Effects and Values, September 2015, i-Tree

Kurn, D., S. Bretz, B. Huang, and H. Akbari. 1994. The potential for reducing urban air temperatures and energy consumption through vegetative cooling. ACEEE

Summer Study on energy efficiency in buildings, American Council for and Energy Efficient Economy. Pacific Grove, California

Lawrence, H. W. (2006). City trees, a historical geography from the renaissance through the nineteenth century. Charlottesville: University of Virginia.

Macie, E. Urban forests: the benefits outweigh the costs. Extension. USFS Southern Region. Articles.extension.org/pages/67787/urban-forests:-the-benefits-outweigh-the-costs

McPherson, G., Simpson, J. R., Xiao, Q., and Wu, C. 2007. Los Angeles one million tree canopy cover assessment. Albany, CA, USA: Department of Agriculture, Forest Service, Pacific Southwest Research Station, Center for Urban Forestry Research.

McPherson, G., Rowntree, R. 1993. Energy conservation potential of urban tree planting. Journal of Arboriculture. 19(6).

McPherson, G., Simpson, J., Peper, P., Maco, S., Xiao, Q. 2005. Municipal forest benefits and costs in five US cities. Journal of Forestry. 103, 8; Research Library pg. 411.

McPherson, E.G., P.L. Sacamano, and S. Wensman. 1993. Modeling benefits and costs of community tree plantings. USDA Forest Service, Northeastern Forest Experiment Station, General Technical Report, Davis, CA.)

McPherson, E.G., Simpson, J.R., Peper, P.J., Maco, S.E., and Xiao, Q. 2005. Municipal forest benefits and costs in five US cities. Journal of Forestry 103(8):411-416

Mizuno, M., Nakamura, M., Murakami, H., and Yamamoto, S. 1990/91. Effects of land use on urban horizontal atmospheric temperature distribution. Energy and Buildings 15-16: 165-176

Nowak, D.J. and E.G. McPherson. Quantifying the impact of trees: The Chicago Urban Forest Climate Project. Unasylva – No. 173 – Urban and peri-urban forestry

Parker, J.H. 1983. Landscaping to reduce the energy used in cooling buildings. J. For. 81(2): 82-84

Pincetl, S., Gillespie, T., Pataki, D., Saatchi, S., Saphores, J. 2013. Urban tree planting programs, function or fashion? Los Angeles and urban tree planting campaigns. GeoJournal. 78:475-493.

Roman, Lara A.; Battles, John J.; McBride, Joe R. Urban Tree Mortality: a Primer on Demographic Approaches. USDA. Department of Agriculture Forest Service. Northern Research Station. General Technical Report NRS-158. 2016.

Saito, I., Ishihara, O., Katayama, T. 1990/91. Study of the effect of green areas on the thermal environment in an urban area. Energy and Buildings 15-16: 493-498

Ulrich, R.S. 1984. View through a window may influence recovery from surgery. Science 224: 420-421.)

Vidal, J. Trees may increase pollution on city streets. The Guardian. Environment. 2016. Theguardian.com/environment/2016/dec/01/trees-may-increase-pollution-on-city-street